Fast Access Spacecraft Testbed (FAST)

Industry Day Briefing

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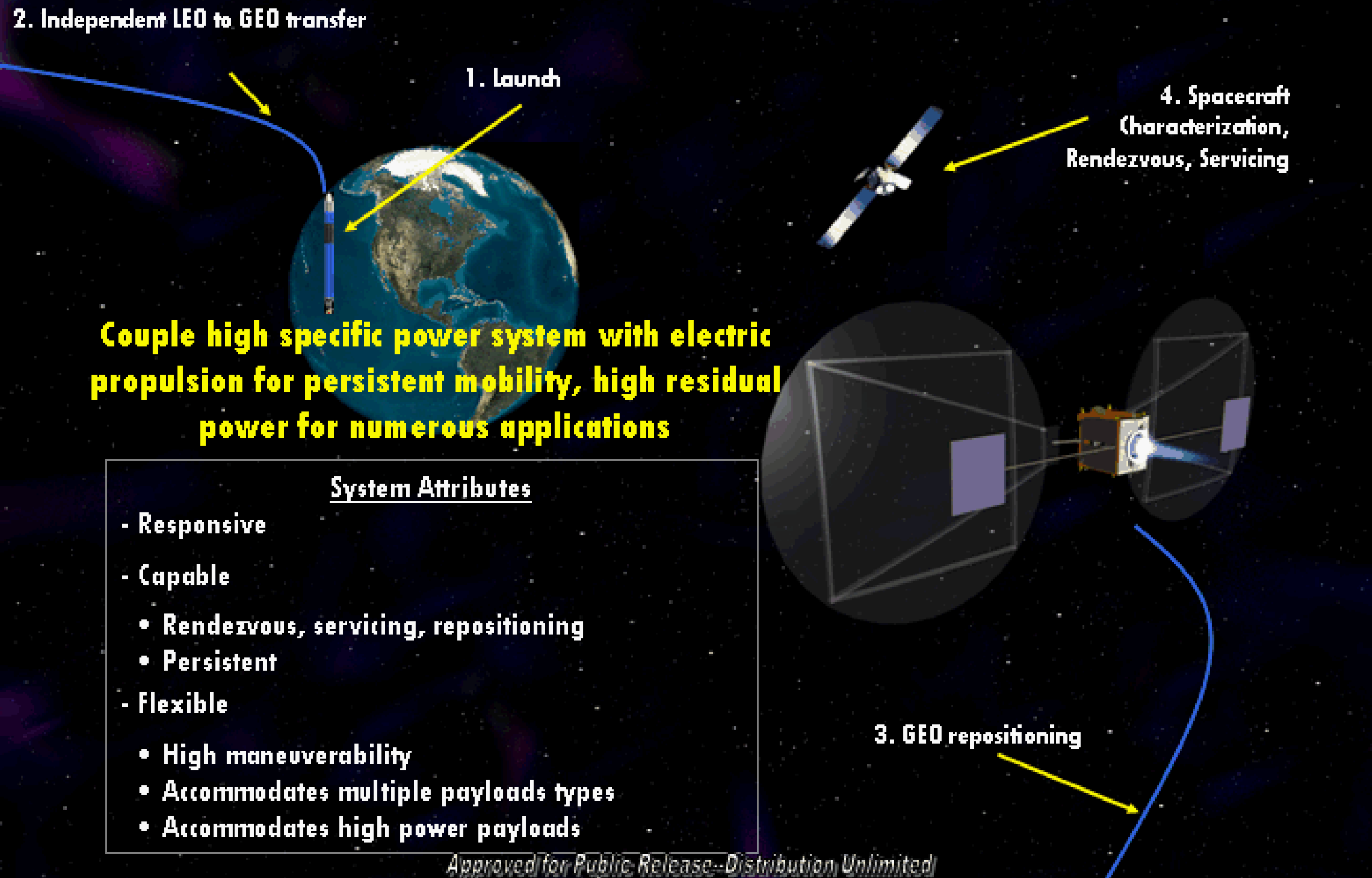
Motivation



Couple high specific power system with electric propulsion for persistent mobility, high residual power for numerous applications

System Attributes

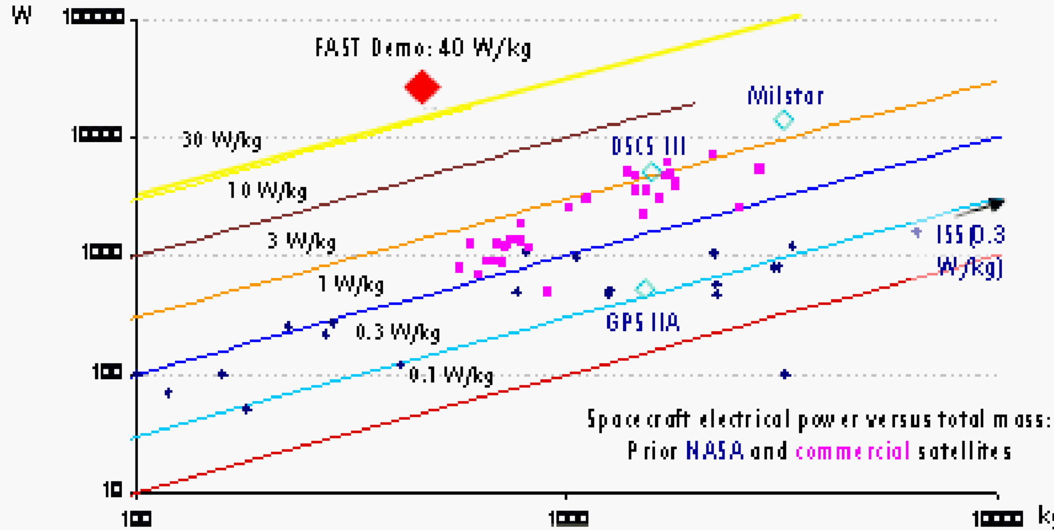
- Responsive
- Capable
  - Rendezvous, servicing, repositioning
  - Persistent
- Flexible
  - High maneuverability
  - Accommodates multiple payloads types
  - Accommodates high power payloads

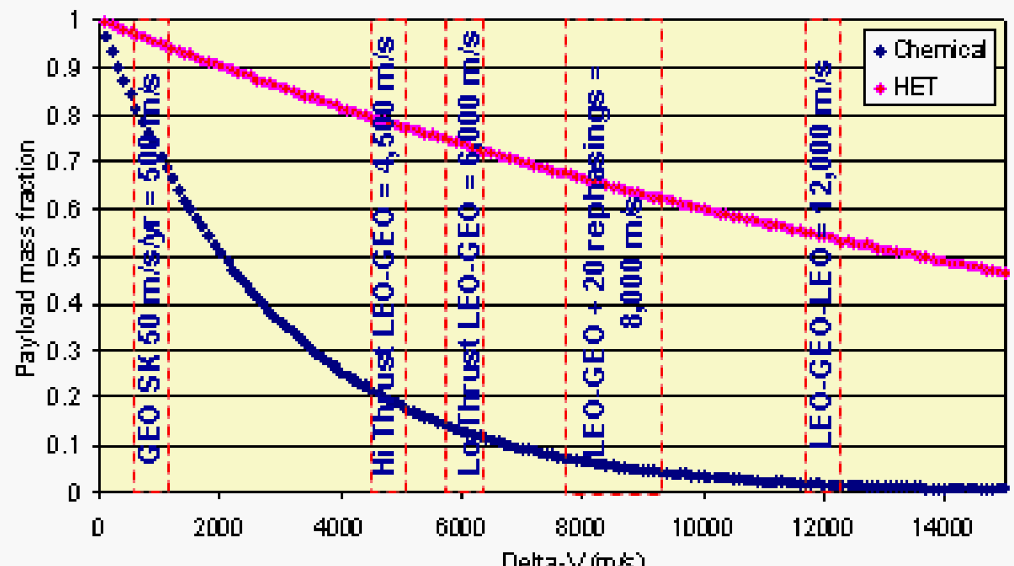
What is FAST?

- Technology Development Program
  - High Power Generation Subsystem (HPGS)
  - Delivers very high specific power: 130 W/kg (HPGS only), 40 W/kg (spacecraft)
  - 20 kWe total (EOL) for demo, should prove out scalability to higher power; 50-80 kWe or more envisioned for operational system
- Phase 1
  - Develop 130 W/kg, 20 kWe HPGS preliminary design
  - Performance simulation of complete HPGS
    - Address sun pointing and tracking effects on performance
  - Complete ground demonstration test plan in a relevant environment, to include all elements of the high power generation subsystem (HPGS):
    - Solar concentration
    - Solar collection
    - Power conversion and
    - Power distribution
    - Heat rejection
    - Structures
    - Deployment devices
    - Sun pointing
    - Sun tracking capability
  - Assess HPGS interfaces with prospective payloads and propulsion systems.
- Phase 2
  - Fabrication, assembly and end-to-end testing of the prototype HPGS in a relevant (i.e., simulated space) environment.

Today's State of the Art (SOTA)

- **Current on-orbit power system performance**
  - ≤ 3 W/kg (spacecraft)
  - Planar arrays with solar cell efficiencies of up to 25%
  - HS702: First halting attempts at concentrators (< 1.8:1 CR)
  - Low voltage (28 V) power distribution, heavy harness
- **Current propulsion system performance**
  - Most systems use chemical mono- and bipropellants, some use low-power ion and Hall thrusters for stationkeeping (< 50 m/sec/year)
- **Where would we have to mature SOTA to in order to be useful?**
  - 40 W/kg** permits 50 kWe, 1,250 kg system to move LEO-GEO in 30 days
  - 40 W/kg** allows 50 kWe system to perform 180 degree transfers in GEO belt in under 7 days





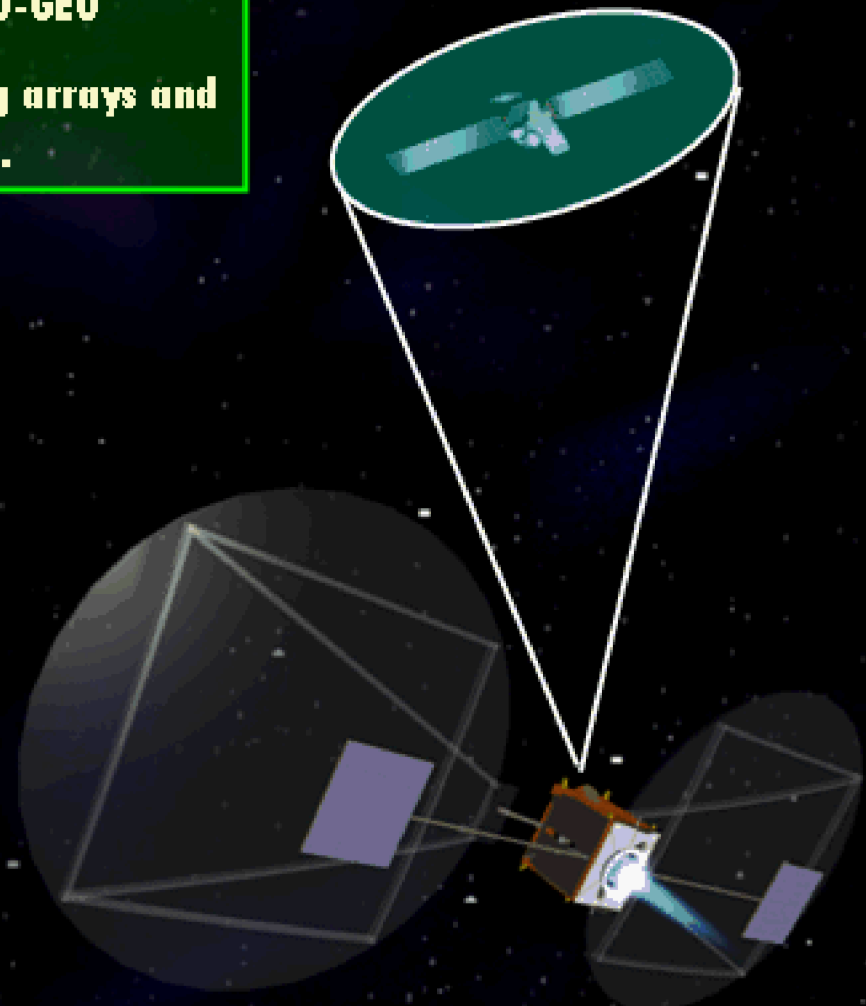
A Focus On High Specific Power

- Seedling showed positive results at 40 W/kg (spacecraft)
  - Allows fast transfers LEO-GEO, rapid repositioning capability in GEO
- FAST will drive the high power generation subsystem state of the art to 130 W/kg (HPGS only)
  - Solar power collection elements, including concentration elements
  - Solar power conversion elements
  - Electrical power management and distribution systems, assuming payload line voltage requirements of no less than 100 V
  - Heat rejection elements required to dissipate waste heat produced in the conversion of sunlight to electricity in the space environment
  - All supporting structures, including pointing and deployment mechanisms and sensors
- Demonstrate a 20 kWe (EOL) architecture that can scale up to 80 kW at 130 W/kg

FAST Seedling Concept Vehicle

A revolutionary approach to achieving high power—and thus significantly increased mobility—in all orbits, LEO-GEO

Approach: Large, low areal density concentrating arrays and small solar cell panels replace heavy SOTA panels.



Electrical Power Production

- Deployable concentrator (< 0.5 kg/m^2)
- High concentration ratio (40:1 to 100:1)
- 50 kWe at 30% photovoltaic cell efficiency
- 40 W/kg spacecraft specific power (>10x SOTA)

Propulsion

- High I_{sp} electric thrusters (e.g., HET)
- Low propellant mass

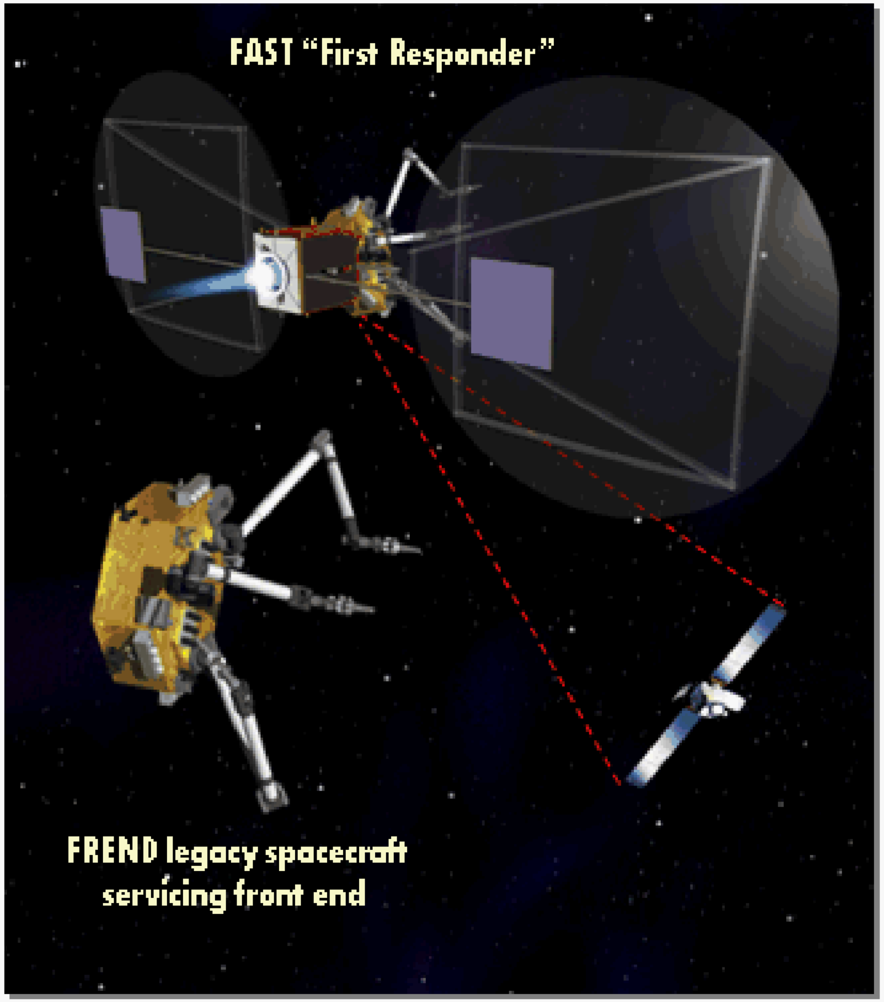
Spacecraft (operational version)

- 1,250 kg wet mass in LEO
- 920 kg to GEO in under 30 days
- 50 kW for payload operations

Spacecraft (proposed demonstrator)

- 570 kg wet mass in LEO (Falcon I/MINOTAUR launch)
- 420 kg in GEO in under 30 days
- 20 kWe for payload operations, 10 GEO rephase moves

Vision: A "First Responder" in MEO/GEO

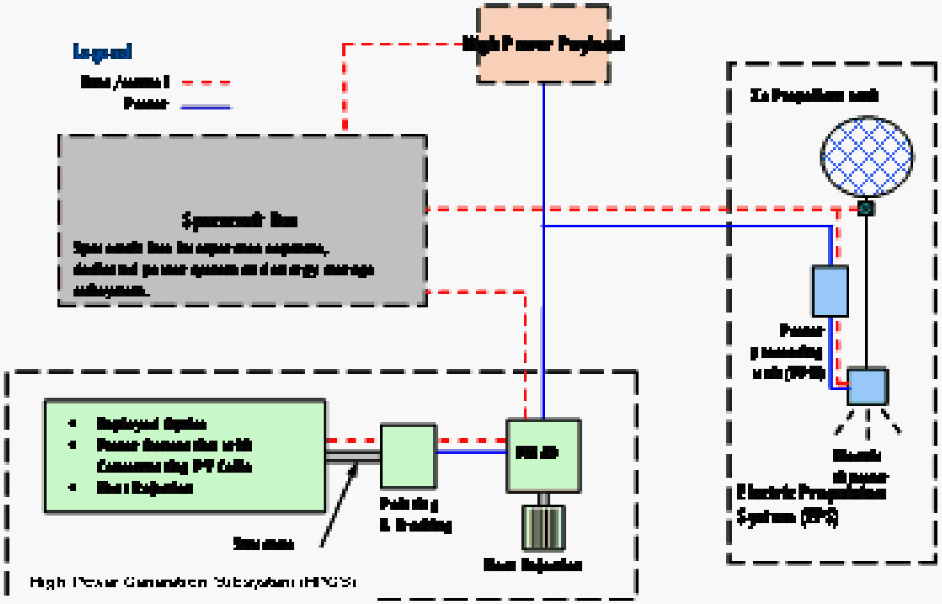


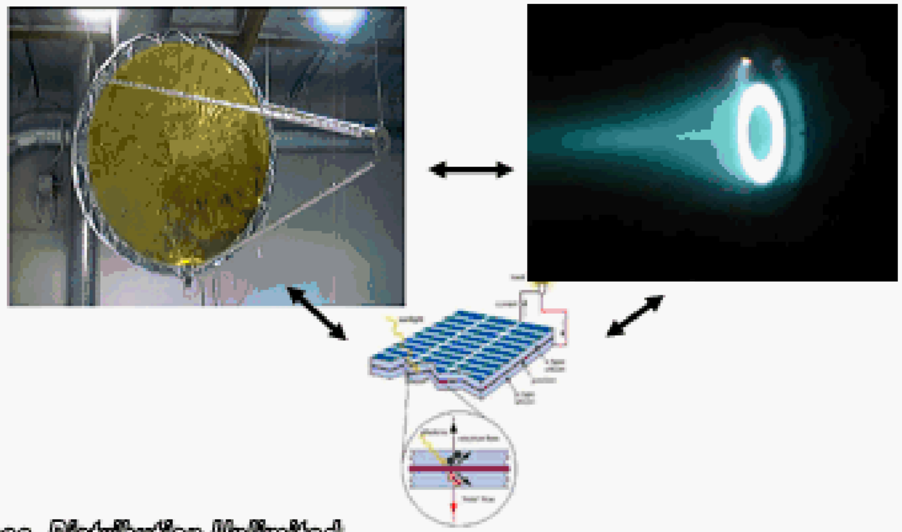
- **Servicing ("OE on Steroids")**
  - Builds on Orbital Express legacy
  - Incorporates FREND legacy spacecraft docking and servicing features
  - Any spacecraft could be serviced/boosted/repositioned
- **Client Vehicle Characterization**
  - Can perform long-standoff client characterization with high-power (50-80 kWe) radar, lidar
  - Can transition to proximity operations for more detailed customer vehicle diagnosis
- **Rapid Response**
  - Rapid maneuver in high orbit permits the First Responder to approach and diagnose client asset anomalies

Compelling missions in high orbit demand new power and propulsion capabilities

FAST System

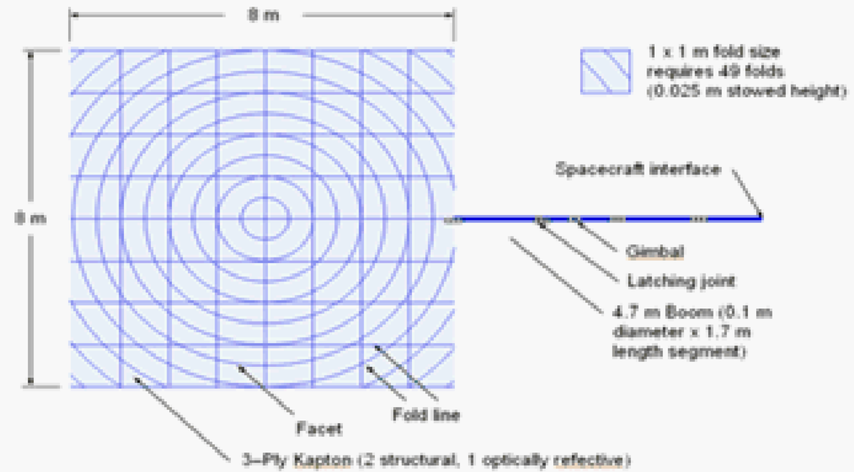
- Concentrators, PV arrays, radiators, Power Mgmt/Distribution, and thruster subassemblies can be traded to reduce overall system risk
- Key challenge is system-level integration and performance characterization of these elements
- Specific challenges include:
  - Deployment of concentrator and radiator assemblies
  - Precision sun-pointing and tracking
  - Thermal and electrical interfaces between power system elements
  - Dynamic disturbances during translation
  - Comprehensive thermal modeling of FAST and spacecraft
- Validation will occur at FAST system level in relevant environment (thermal high vacuum, with collimated solar source and integrated propulsion)

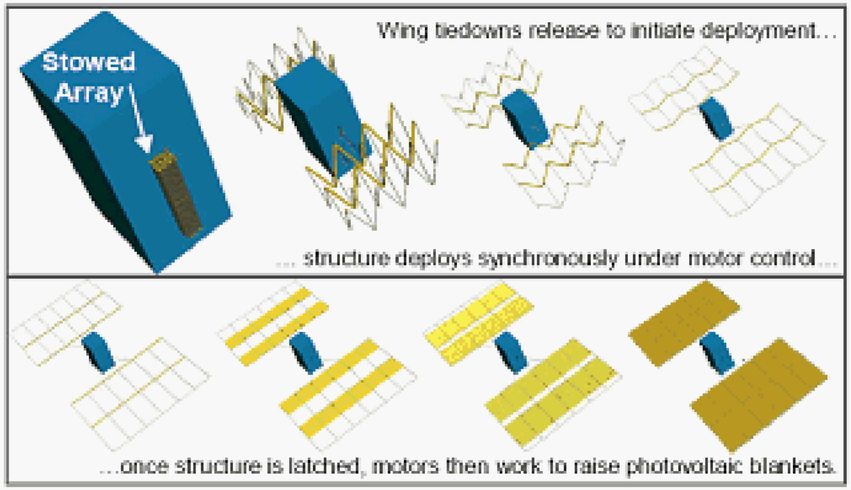




Key Technology Enablers

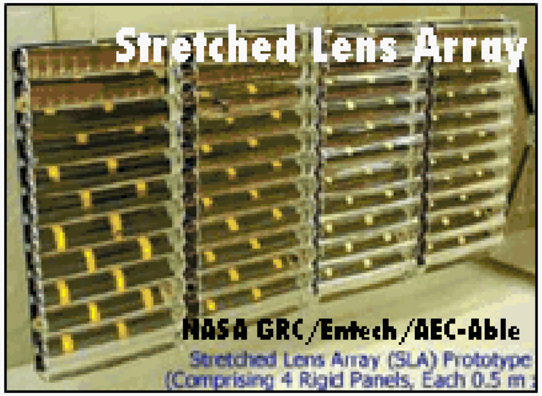
- **Lightweight Solar Energy Concentration**
  - Solar radiation: 1352 W/m^2 (earth orbit)
  - Low areal density (< 0.5 kg/m^2)
  - Requires precision deployment of large stowed structure
  - Cells must survive high flux (40:1 to 100:1) and possibly elevated temperatures
- **Thermal Mangement System**
  - High power → high heat rejection
  - At 50 kWe and 30% efficiency, 120 kWt of waste heat must be rejected at low temp
  - NH_3 pumped loops are heavy, complex
  - Alternatives include advanced technology heat pipes and lightweight C-C radiator fins at operating temperatures > 250 C
- **Power management/distribution**
  - High voltage PMAD, high temp electronics
  - Low weight, broad power range

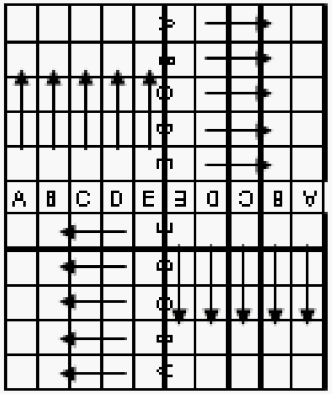




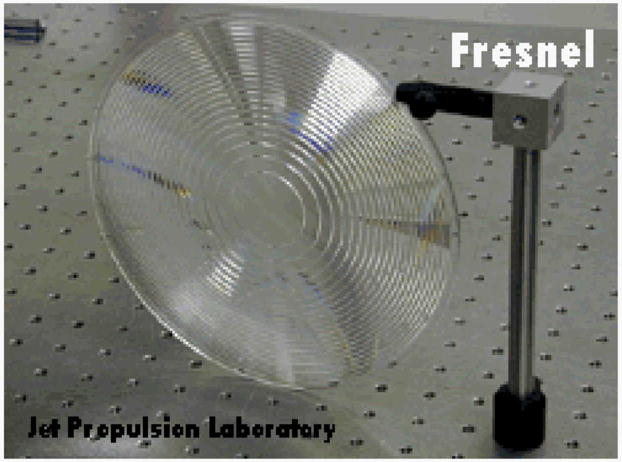
Key Technology: Solar Concentrator

- **Key Requirements**
  - High specific power
  - Package-able for small to medium class launch vehicle
  - Lightweight / large collector area
- **Derived characteristics**
  - Stowable / deployable
  - Concentration ratio (40-100:1)
  - Heat rejection
  - Pointing (< 2 deg/axis)
- **Technology options**
  - Rigid, deployed panels
  - Inflatable torus
  - Stretched lens array



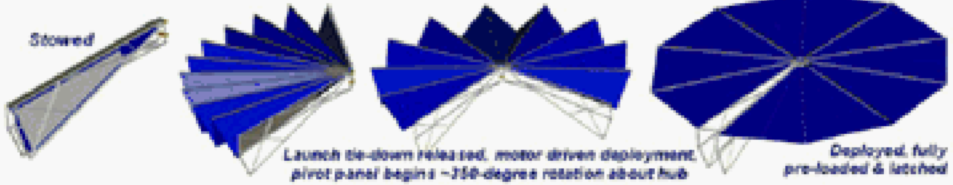


Extruded, Overlaid Fresnel "strips"



Deployable

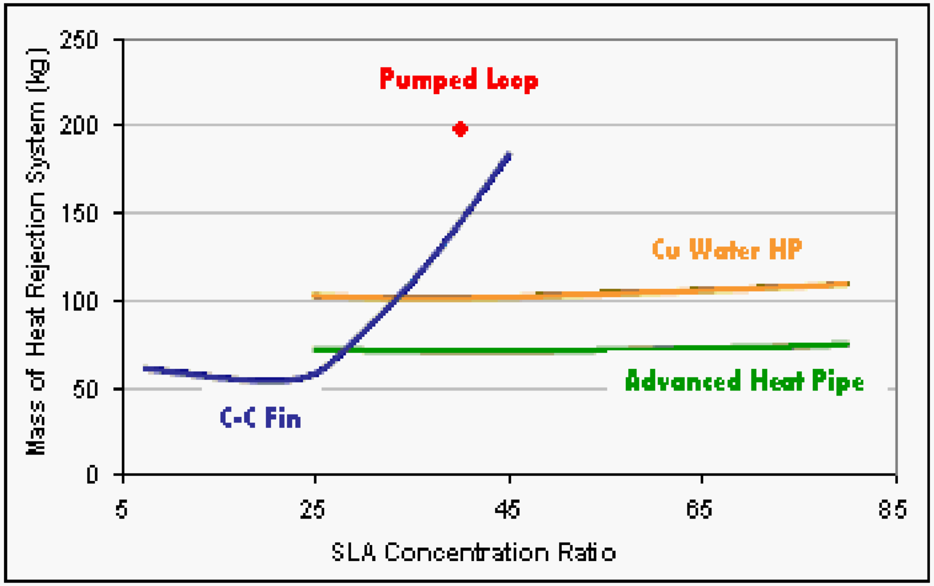
AEC-Able

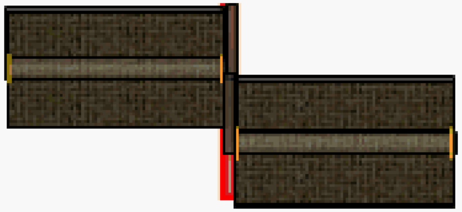


Key Technology: Lightweight Heat Rejection

- **Program objectives**
  - Maintain solar cell arrays within operating temperature limits
  - Lightweight
- **Derived characteristics**
  - 20 kWe power system (FAST Demo)
  - 107 kWt heat rejection
  - Operating temperature < max solar cell operating temperature minus 20 °C
- **Technology options**
  - Radiative Fins (Carbon-Carbon)
  - Conventional Heat Pipe
  - Advanced Heat Pipe
  - Pumped Loop

Heat Rejection System Design Trade





Revolutionary thermal management technology on backside of solar cells

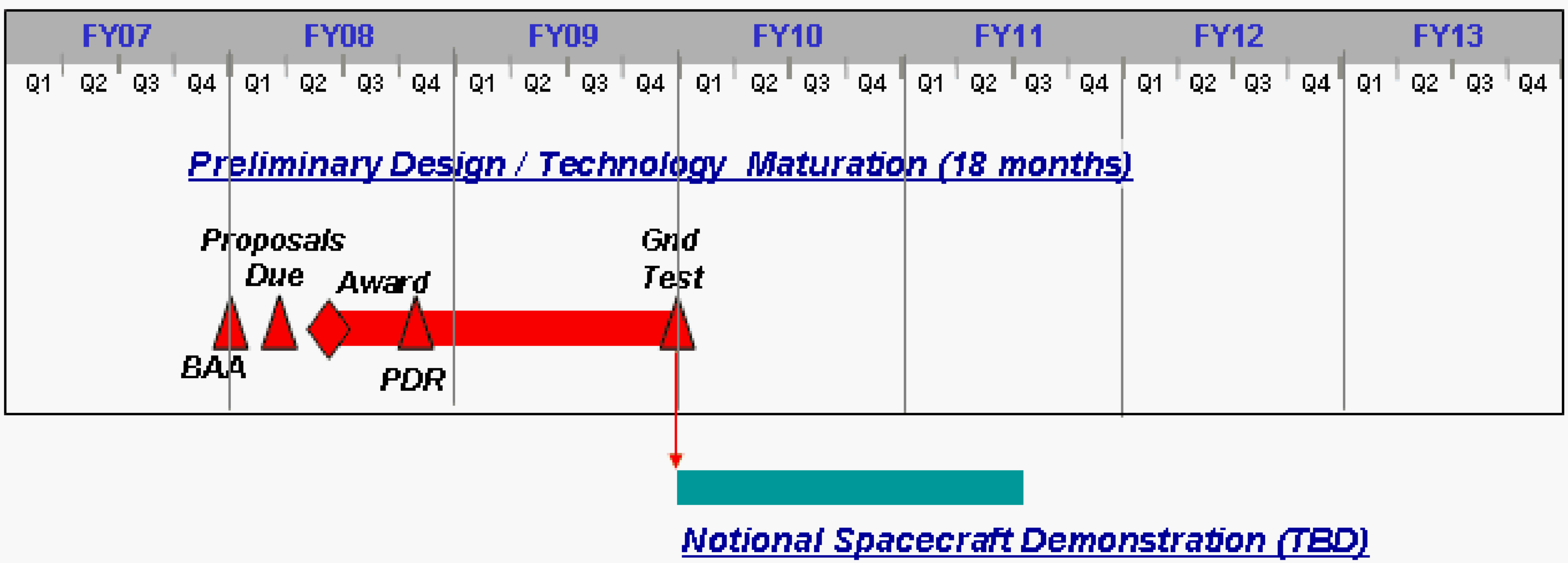
Notional Program Plan

- Phase 1 – HPGS Preliminary Design (~6 months)
  - Preliminary HPGS design complete, including end-to-end ground test demonstration plan
    - Specific Power = 130 W/kg
    - Total Power = 20 kWe
  - Simulation of HPGS performance including solar concentrator, power conversion, heat rejection, structure and deployment, plus sun pointing and tracking effects
  - Assess HPGS interfaces with prospective payloads and propulsion systems
- Phase 2 – HPGS Ground Testing (~12 months)
  - Perform integrated power system ground testing to demonstrate power collection, generation, and heat rejection (PCGR) in representative environment and duration (30 days)
  - Design meets
    - Specific Power = 130 W/kg
    - Total Power = 20 kWe
    - Solar concentrator areal mass of 0.5 kg/m^2
    - Radiator areal mass of 1.0 kg/m^2
  - Show design can scale to 80 kWe (or greater)

Program Funding and Schedule

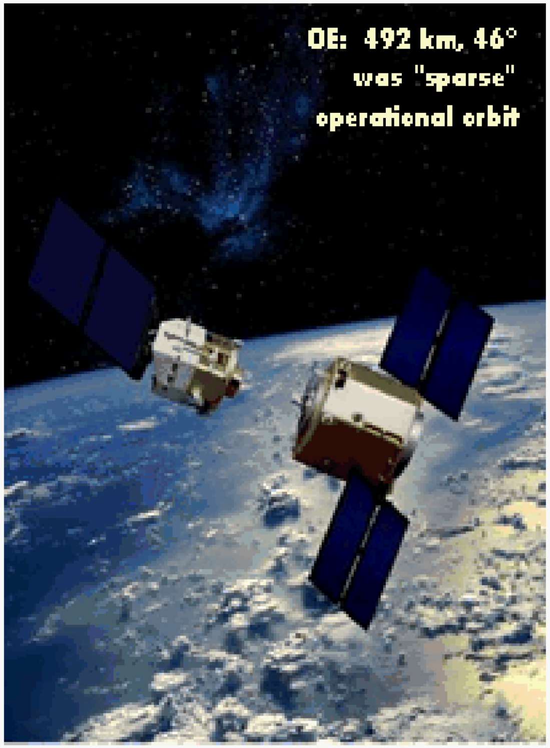
- **Funding**
  - We expect to fund multiple parties through PDR, then downselect to one contractor (this contractor will build and test the HPGS)
- **Events**

– FAST Industry Day	02 Oct 07
– BAA Release	05 Oct 07
– Proposals Due	04 Dec 07
– Award(s)	March 2008



BACKUP

Mobility



- Extremely limited at present
  - Most onboard propulsion used for drag compensation, stationkeeping, some rephasing in GEO (e.g., life-limiting DSCS move during 1991 Desert Storm campaign)
  - Electrical propulsion proven on-orbit for reaction control, some stationkeeping
  - Insufficient power to use EP as orbit transfer system
- Example: Orbital Express
  - Two major objections from AF, NRO
    - System cannot service legacy spacecraft
    - System cannot reach objects of interest (insufficient mobility)
- FAST changes the equation
  - Combination of high delta-V (> 6 km/sec) and high power allow FAST-enabled s/c to:
    - Launch to LEO and move to GEO (6 km/sec) in one month or less
    - Numerous 180 degree rephasing maneuvers in GEO, one week per move or less (< 100 m/s)
    - Can move between any sun-synchronous orbit between 300 and 5,000 km (inclinations of 96 – 138°)